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**EFFECT OF GYRO VERTICALITY ERROR ON
LATERAL AUTOLAND TRACKING PERFORMANCE
FOR AN INERTIALLY SMOOTHED CONTROL LAW**

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. JUNE 1977



0152182

1 Report No NASA TM X-3545		2 Government Accession No		3 Recipient's Catalog No	
4 Title and Subtitle EFFECT OF GYRO VERTICALITY ERROR ON LATERAL AUTOLAND TRACKING PERFORMANCE FOR AN INERTIALLY SMOOTHED CONTROL LAW				5 Report Date June 1977	
				6 Performing Organization Code	
7 Author(s) Jerry J. Thibodeaux				8 Performing Organization Report No L-11428	
9 Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665				10 Work Unit No 513-52-01-19	
				11 Contract or Grant No	
12 Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546				13 Type of Report and Period Covered Technical Memorandum	
				14 Sponsoring Agency Code	
15 Supplementary Notes					
16 Abstract <p>This report presents the results of a simulation study performed to determine the effects of gyro verticality error on lateral autoland tracking and landing performance. A first-order vertical gyro error model was used to generate the measurement of the roll attitude feedback signal normally supplied by an inertial navigation system. The lateral autoland law used here was an inertially smoothed control design. The effect of initial angular gyro tilt errors (2°, 3°, 4°, and 5°), introduced prior to localizer capture, were investigated by use of a small perturbation aircraft simulation. These errors represent the deviations which could occur in the conventional attitude sensor as a result of the maneuver-induced spin-axis misalignment and drift. Results showed that for a 1.05° per minute erection rate and a 5° initial tilt error, "ON COURSE" autoland control logic was not satisfied. Failure to attain the "ON COURSE" mode precluded high control loop gains and localizer beam path integration and resulted in unacceptable beam standoff at touchdown.</p>					
17 Key Words (Suggested by Author(s)) Control systems Automatic landing systems Vertical gyros			18 Distribution Statement Unclassified - Unlimited Subject Category 08		
19 Security Classif (of this report) Unclassified	20 Security Classif (of this page) Unclassified	21 No of Pages 18	22 Price* \$3.50		

EFFECT OF GYRO VERTICALITY ERROR ON
LATERAL AUTOLAND TRACKING PERFORMANCE FOR AN
INERTIALLY SMOOTHED CONTROL LAW

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SUMMARY

This report presents the results of a simulation study performed to determine the effects of gyro verticality error on the simulated lateral autoland tracking and landing performance of a small twin-jet short-haul commercial transport. A vertical gyro error model was used to generate the roll attitude signal which was used with the inertially smoothed control law in a small perturbation simulation. The influence of initial angular gyro tilt errors (2° , 3° , 4° , and 5°) introduced prior to localizer capture for a 1.05° per minute gyro erection rate was investigated. These errors were used to simulate deviations which may occur in the attitude sensor as a result of the cumulative effects of maneuver-induced spin-axis misalignment and drift. Results showed that for a 5° initial tilt error, the lateral "ON COURSE" autoland control logic was not satisfied and thereby localizer beam path integration was precluded and unacceptable beam standoff at touchdown occurred.

INTRODUCTION

Throughout the evolution of automatic landing systems for aircraft, it became apparent to designers that landing decision heights could be decreased by means of increased navigation data accuracy. The current impetus toward reduced civil aircraft landing minima has sharply brought into focus the demand for such noise-free highly accurate navigation information in the form of vehicle attitude, position, velocity, and acceleration. The introduction of the microwave landing system (MLS) promises to provide accurate position data. Because of this system, the potential exists for obtaining accurate estimates of position, velocity, and acceleration information for guidance and control by processing MLS data with relatively low-cost onboard sensors such as body-mounted accelerometers and standard attitude gyros. If this potential can be achieved, acceptable automatic landing performance may be attained by using the MLS and low-cost onboard sensors in lieu of high-cost inertial platforms. However, because of new flight techniques for approach to landing which may consist of much terminal area maneuvering, a general concern has arisen as to the effects of maneuver-induced errors of conventional sensors on automatic control systems.

Although it is true that inertial systems have fulfilled the data accuracy requirements, expensive purchasing and maintenance costs are discouraging to aircraft operators to say the least. Thus, a simulation study was undertaken

to investigate the lateral performance of an inertially smoothed control law by using a conventional vertical gyro which simulated maneuver-induced tilt errors. It was assumed in this study that other guidance data such as lateral position, velocity, and acceleration information were accurately obtained. In other words, no error models were incorporated for these data in the simulation.

The purpose of this paper is to present the results of a study showing the influence of simulated maneuver-induced gyro verticality error on the lateral tracking performance of an automatic landing system of a small twin-jet short-haul commercial transport (fig. 1). Reference 1 provides detailed information on this control law. This class of error occurs in attitude gyros subjected to low-frequency oscillations associated with preapproach maneuvering during curved or decelerating approaches. In particular, tests were directed toward determining the effects of various initial gyro tilt errors (2° , 3° , 4° , and 5°) for a vertical gyro erecting at 1.05° per minute. This erection rate is typical of many of the present-day commercially available vertical gyros. Particular attention was devoted to the lateral tracking performance while on a short 8334 m (4.5 n. mi.) approach. The tilt errors and erection rate were simulated by the use of a first-order vertical gyro error model.

SYMBOLS

Values are presented in both SI and U.S. Customary Units. Calculations were made in U.S. Customary Units.

\ddot{c}	local level acceleration, g units
g	acceleration constant due to gravity, m/sec ² (ft/sec ²)
h	altitude, m (ft)
h_R	radio altitude, m (ft)
K_η	filter gain
$K_{\psi G}$	gain on ground heading through transient-force gain changer
s	Laplace transform
V	total airspeed, m/sec (ft/sec)
V_G	total groundspeed, m/sec (ft/sec)
X, Y	x- and y-coordinates in X and Y Earth axes, m (ft)
\dot{Y}	cross-track velocity, m/sec (ft/sec)
β	glideslope error, deg
δ_a	aileron position, deg

δ_{ac}	aileron command, deg
δ_e	elevator position, deg
δ_{ec}	elevator command, deg
δ_r	rudder position, deg
δ_{sp}	spoiler position, deg
δ_{stab}	stabilizer position, deg
δ_t	thrust, N (lb)
δ_{tc}	thrust command, N (lb)
η	angular displacement, deg
η_{EST}	filtered angular displacement, deg
η_{LOC}	localizer beam angular displacement, deg
η_p	angular displacement that has been gain programed as a function of altitude, deg
θ	pitch attitude, deg
τ	time constant, sec
ϕ	true roll attitude, deg
ϕ_c	bank angle command, deg
ϕ_m	measured roll attitude from vertical gyro model, deg
ψ	heading, deg
ψ_G	ground heading, deg

Subscripts:

ILS	instrument landing system
lim	limit

Dots (·) over symbols indicate differentiation with respect to the independent variable time.

A caret (^) over a symbol denotes output of minimum value discriminator.

SIMULATION PROGRAM

A block diagram of the simulation program is shown in figure 2 and consists of the inertially smoothed control laws and servo dynamics into which thrust, aileron, and elevator commands were input. Linear aircraft equations of motion in perturbed state form were written in order to determine vehicle position, velocity, acceleration, and attitude information. These equations were written to form the vehicle model used in the flight critical control laws to compute errors from the desired flight. This study was conducted by use of a digital simulation of a small twin-jet research aircraft whose systems are described in references 2 and 3. The trajectory for this study was a 61.73 m/sec (120-knot), 3° descent to touchdown. Based on these deviations from this trajectory, control commands were introduced to the respective servos of the vehicle control system. Utilization of roll attitude feedback was made after being corrupted by the vertical gyro error model. Shown in figure 2 are the blocks representing the longitudinal and lateral autoland systems. Spoiler input was formulated by a 1.73 gain on the aileron signal. First-order lag models were used to describe engine thrust response. The control signals thus derived together with the yaw damper output were introduced into the aircraft perturbation equations of motion which were written in state variable form.

The perturbation states in vehicle stability axes were pitch attitude θ , normalized inertial velocity u' , angle of attack α , pitch rate q , bank angle ϕ , heading ψ , sideslip β , roll rate p , and yaw rate r . The control vector consisted of perturbed elevator position δ_e , perturbed stabilizer position δ_{stab} , perturbed thrust δ_t , perturbed aileron position δ_a , perturbed spoiler position δ_{sp} , and perturbed rudder position δ_r . Aerodynamic data were obtained by use of a data program package at the Langley Research Center for the aircraft in the landing configuration, that is, gear down, flaps 40° down, 61.73 m/sec (120 knots) airspeed, and a weight of 400 kN (90 000 lb).

Gyro Error Model

Figure 3 is a block diagram showing the fundamental elements of the single degree of freedom vertical gyro error model. The errors associated with a conventional vertical gyro (ref. 4) are a result of three distinct effects:

(1) Cumulative drift effects: Because of mass unbalance, bearing friction, Earth rotation rate, and coriolis acceleration, the gyro spin axis becomes misaligned with the true local vertical.

(2) Maneuver-induced spin-axis alignment with a false vertical: During periods of accelerated flight (forward or centripetal acceleration present), the gimbal-mounted electrolytic bubble sensors cause the gyro to be aligned with a false vertical. This false or apparent vertical is the vector addition of vehicle acceleration and gravity.

(3) Propagation error in turns: This effect predominantly occurs in aircraft turns during which time the gyro spin axis tends to maintain a fixed spatial orientation as the airplane and gimbals rotate about the gyro. The result

of this phenomena is that any existing pitch error while on a northern heading translates to a roll error when heading is changed to east or west.

The fundamental components of the gyro model (fig. 3) are the erection rate limiter and cutout and the torque motor. The cutout threshold for these tests was set to a lateral acceleration corresponding to a 6° bank angle. In other words, whenever the apparent lateral acceleration sensed by the roll bubble exceeded the acceleration corresponding to 6° roll, erection cutout occurred. The angular position error is then formed by the addition of the drift and the erection signal from the torque motor. Finally, this error was added to the true attitude for formulation of the measured roll attitude signal.

Tests

The initial setup for this study is shown in figure 4. A relatively short straight-in final approach was used after the aircraft was started at capture in straight and level flight but offset by 365.76 m (1200 ft). It was also given a 20° localizer intercept angle. Initial condition errors between the spin axis and the local vertical (see fig. 3) were injected prior to commencing the problem. All these gyro tilt errors (2° , 3° , 4° , and 5°) were positive, that is, right wing down which simulates a worse case situation. Also, gyro drift and Earth rates were assumed to be positive. Vehicle automatic tracking performance was monitored through touchdown for each tilt error and the selected erection rate. Wind velocity was considered to be zero in these tests.

RESULTS AND DISCUSSION

The lateral autoland tracking performance was examined for a gyro erection rate of 1.05° per minute after initial gyro tilt errors were induced prior to localizer capture. Figure 5 shows the lateral tracking performance when the inertial roll attitude feedback that would be expected from a stabilized platform is used. It is realized that because of preapproach maneuvering, maximum roll attitude errors of the order of 0.1° are possible with stabilized platforms, but in the context of this paper they were considered to be insignificant. In other words, the inertial platform attitude signal was deemed to be perfect. Figures 6 to 9 show the effect of the various tilt errors on the final approach trajectory. Tracking and overshoot errors observed in figures 6 to 8 are due to the initial gyro tilt errors which are not completely eliminated by erection. The lower plot gives the variation of tilt error with respect to time. It should be noted that although the induced lateral displacement errors (due to initial 2° , 3° , and 4° gyro tilt) at touchdown are small, they are systematic and may be significant percentagewise when compared with the influence of other environmental and landing system errors. For the 5° tilt error (fig. 9), unacceptable standoff and divergence from the runway center line were observed. The lateral touchdown dispersion for 2° , 3° , and 4° tilt errors are plotted in figure 10 and vary from -0.45 m (-1.47 ft) to -0.53 m (-1.74 ft). For the 5° tilt error where the control logic was not satisfied, the lateral deviation at touchdown was 101.98 m (334.57 ft) and is unacceptable.

The behavior of figure 9 can be understood if the lateral autoland control loop (fig. 11) is studied. Three logic criteria must be satisfied in order to acquire the "ON COURSE" state. In order to satisfy all criteria ("ON COURSE" set to true in the simulation), the localizer beam angle must be less than η_{lim} (see insert (A) in fig. 11) and the beam rate less than 0.027° per second. Also, the bank angle must be less than 3° . When all criteria are satisfied, "ON COURSE" is set to true and the appropriate switch closures result. Of these three criteria, the last two are readily satisfied; however, the first requirement depends on beam deviation and may or may not be satisfied depending on the tilt error encountered at localizer capture. Because the beam acceptance limit η_{lim} is a function of altitude and decreases rapidly relative to tilt error reduction, it was found that the localizer angular displacement η did not become sufficiently small compared with η_{lim} for the 5° tilt error. As a result, the localizer beam integration loop whose primary function is to reduce the steady-state beam displacement error to zero is never incorporated into the control law. Also, the high loop gains (inserts (C) and (D) in fig. 11) are not attained; thereby less precise tracking and unacceptable beam standoff at touchdown result.

CONCLUDING REMARKS

The results of this study indicate that vertical gyro tilt errors, which may be substantial because of terminal area maneuvering and gyro imperfections, can degrade lateral autoland tracking performance measurably. In addition, for the control law examined, there is an error threshold which, if exceeded, precludes localizer capture because the "ON COURSE" logic criteria could not be satisfied.

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May 6, 1977

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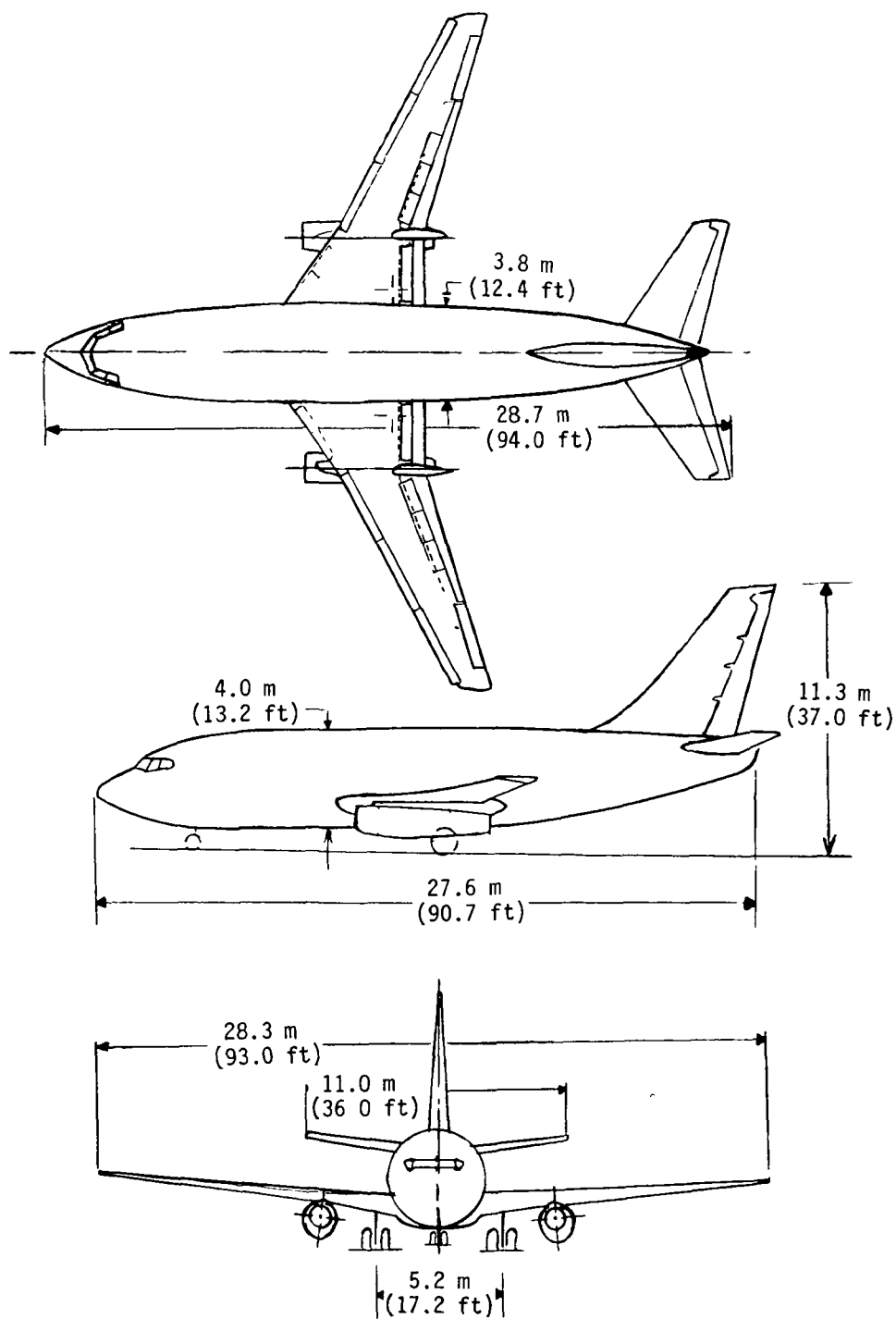


Figure 1.- Dimensions of simulated aircraft.

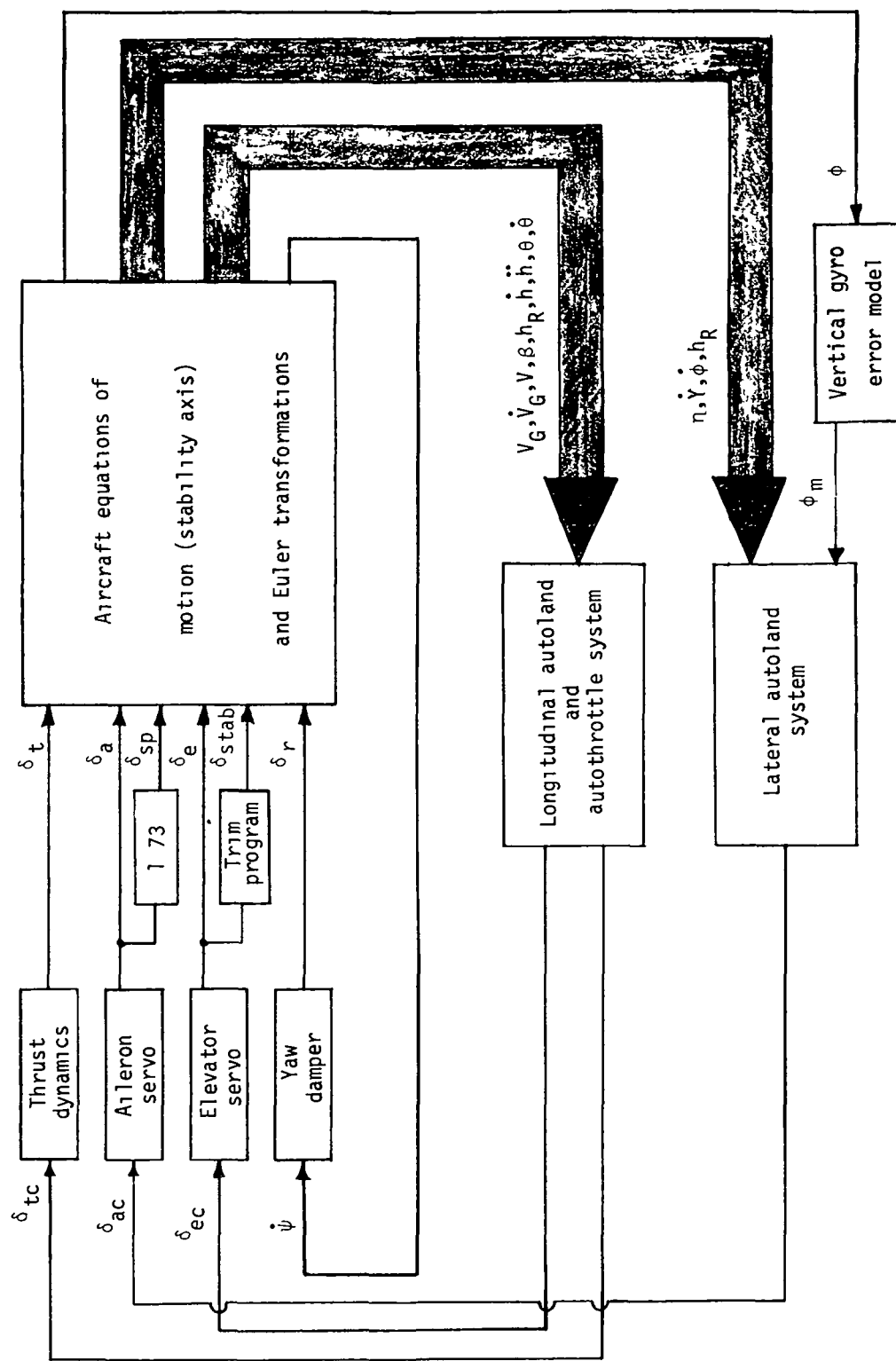


Figure 2.- System block diagram.

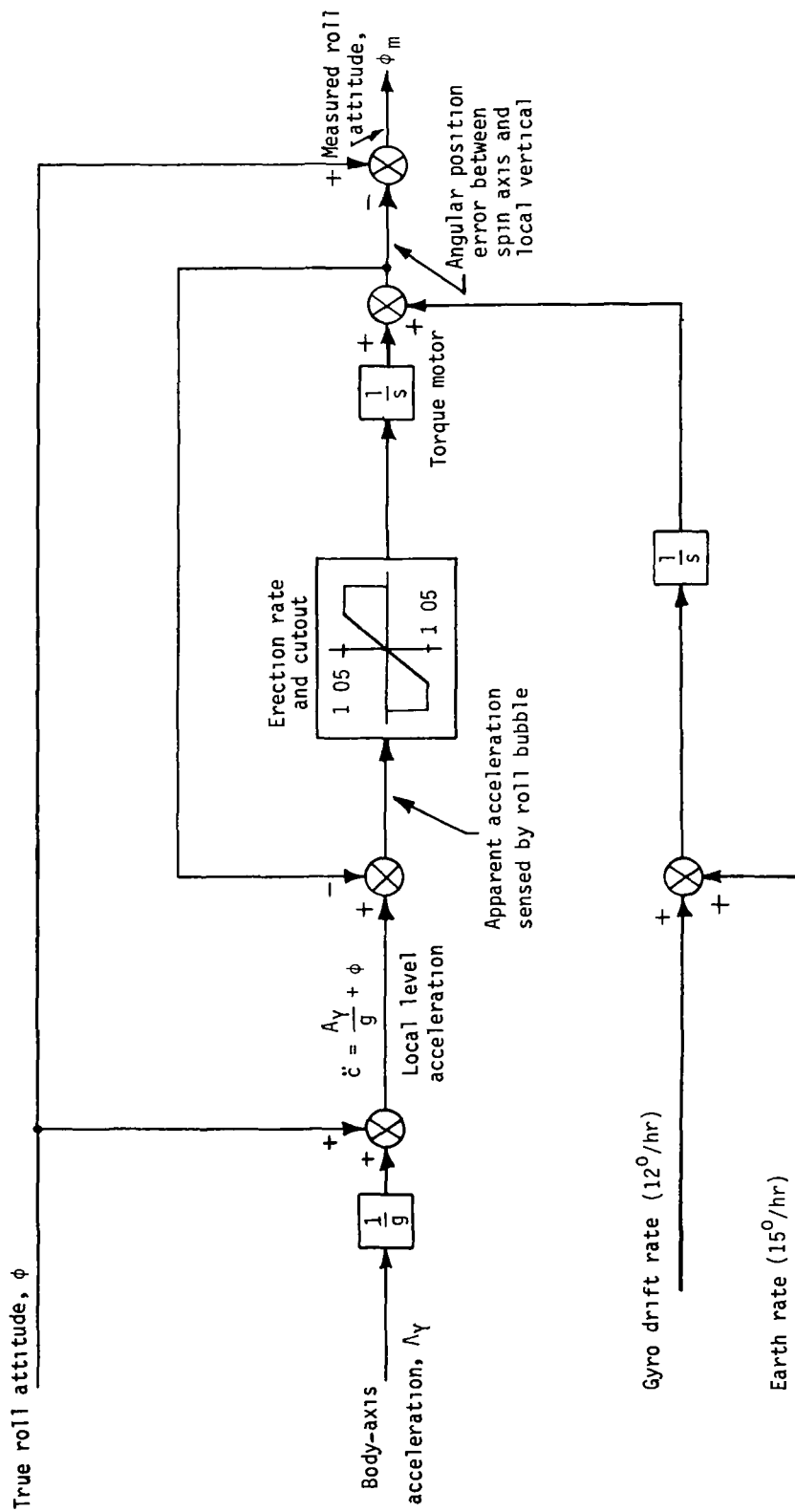


Figure 3.- Lateral degree of freedom vertical gyro model.

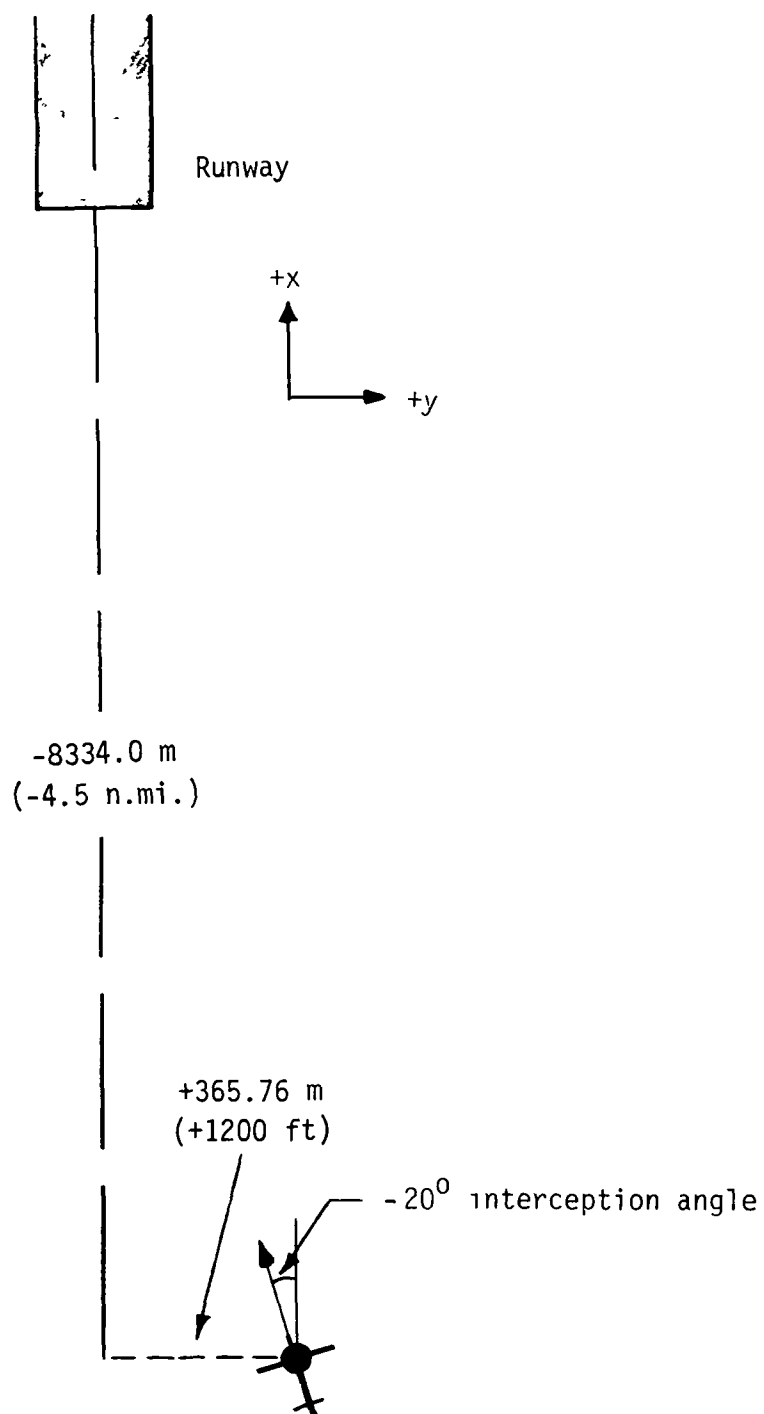


Figure 4.- Test situation and sign convention.

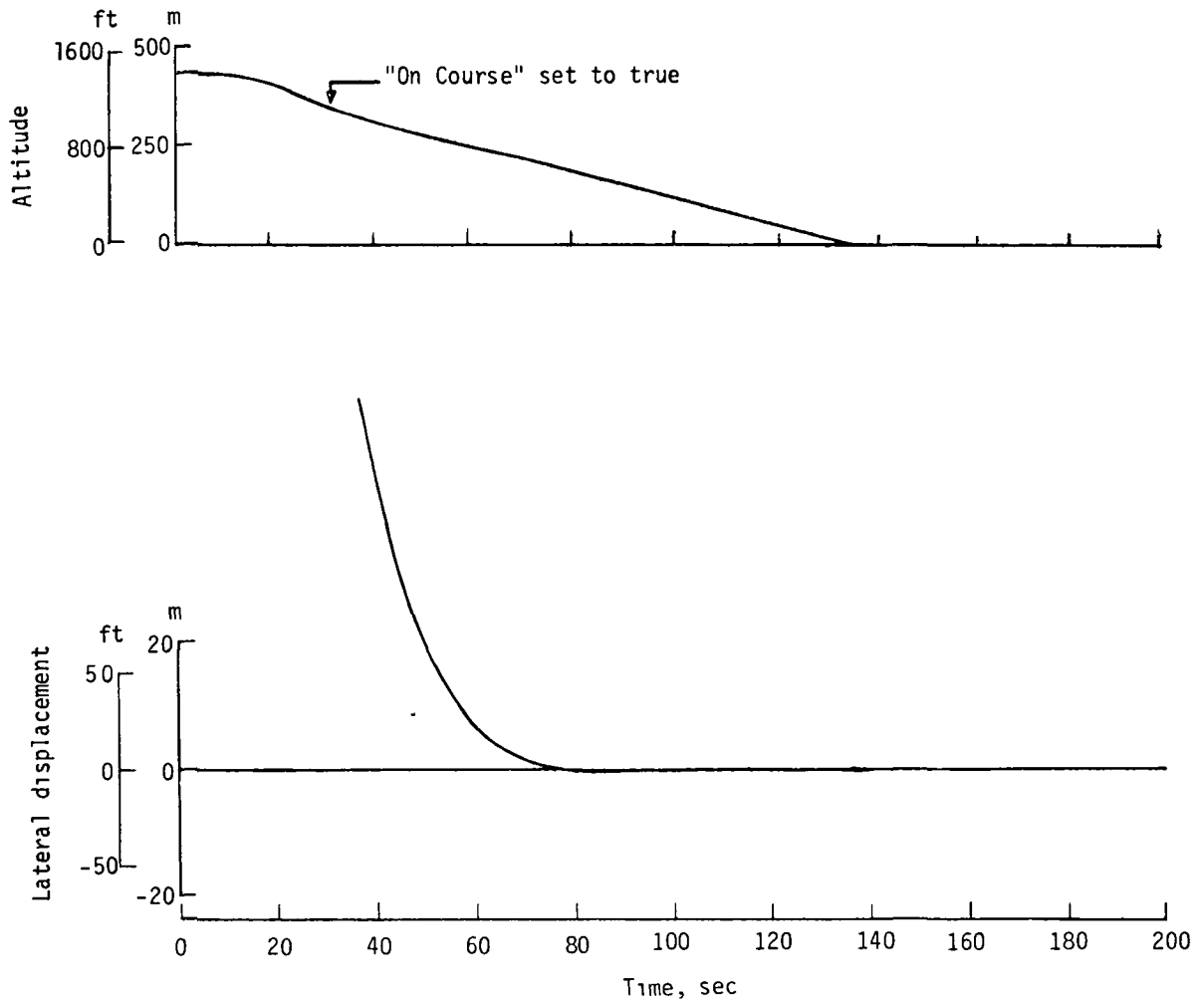


Figure 5.- Lateral tracking performance using inertial roll attitude feedback.

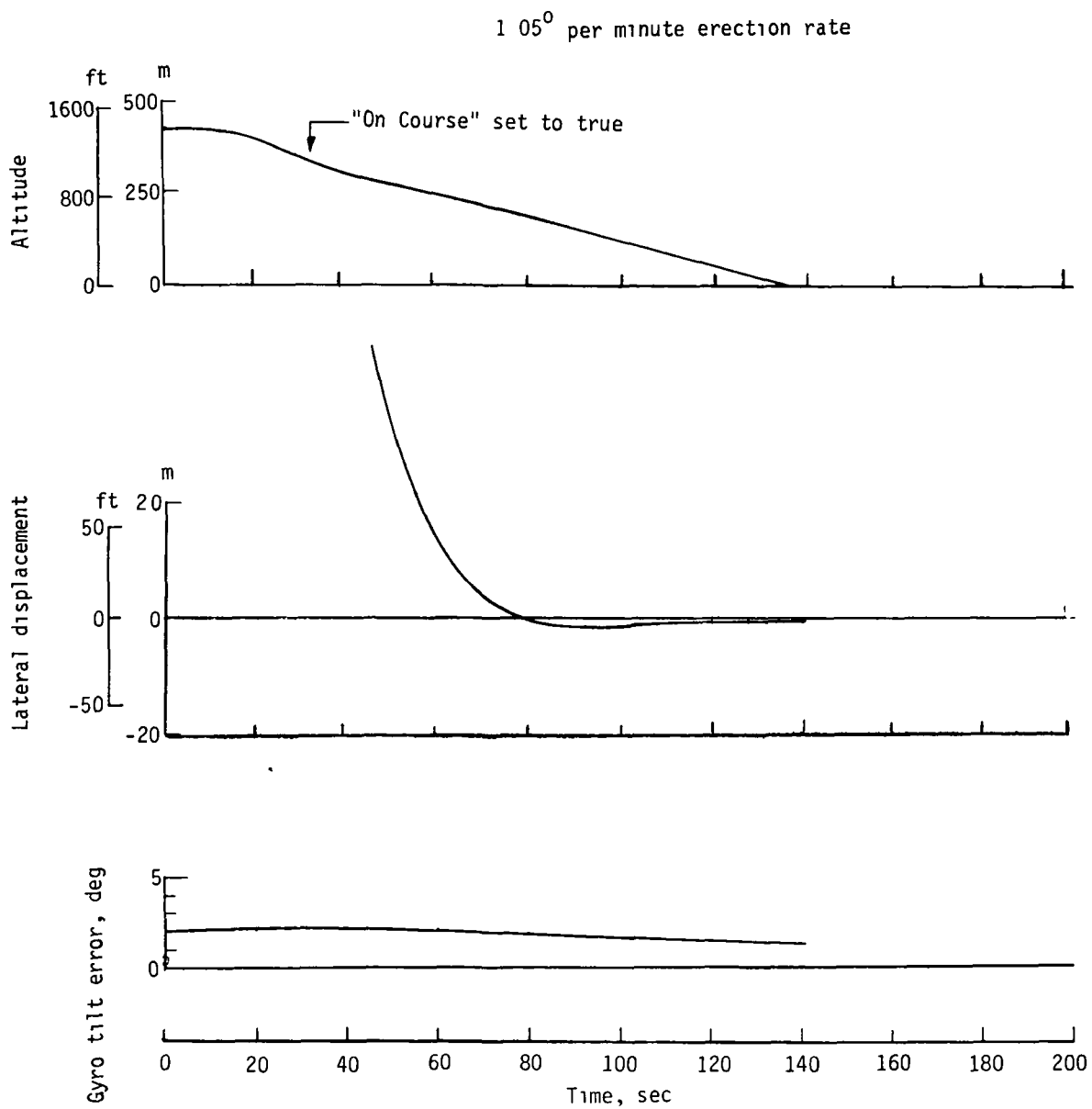


Figure 6.- Lateral tracking performance for a 2° vertical gyro tilt error prior to localizer capture.

1 05° per minute erection rate

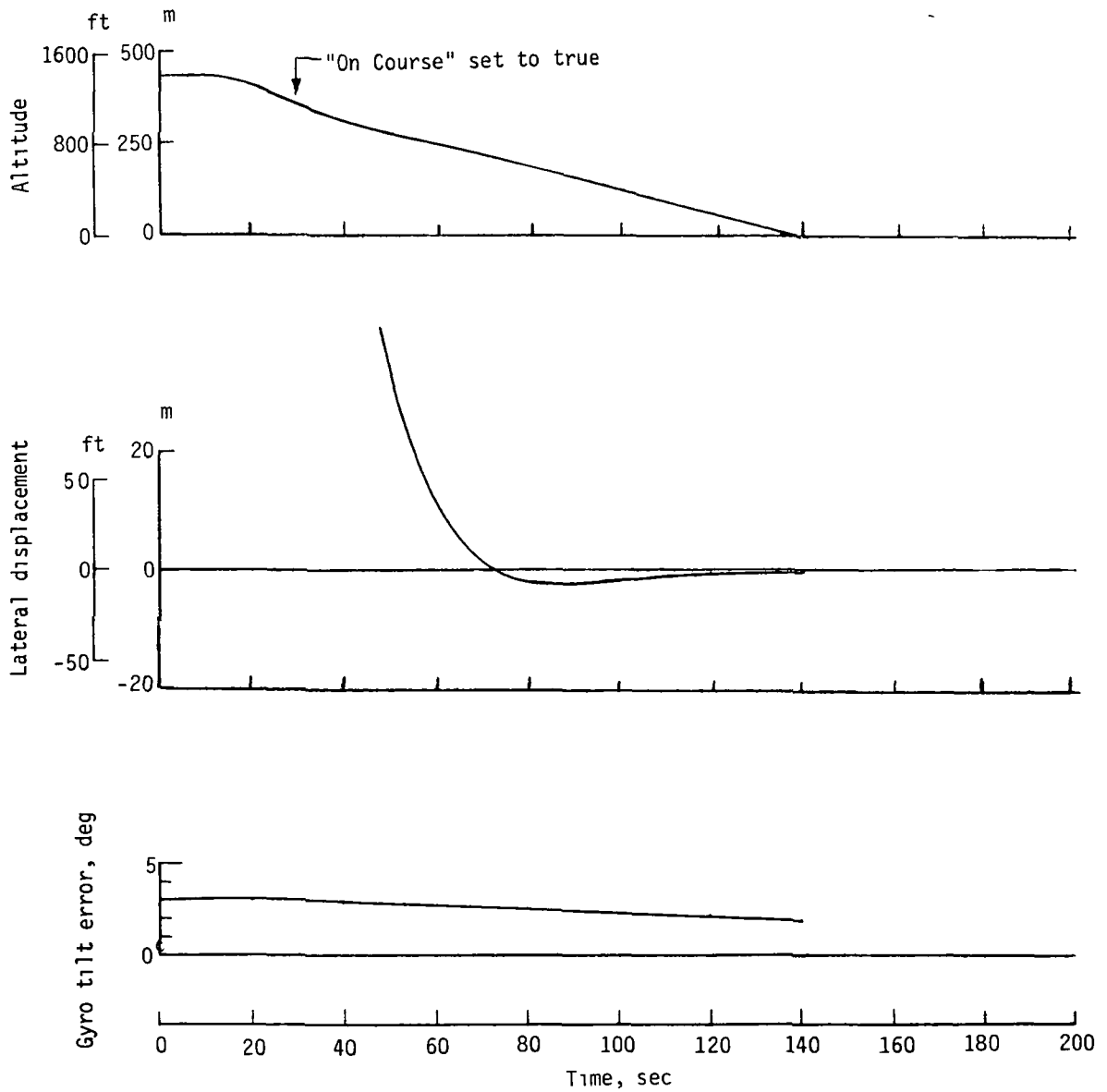


Figure 7.- Lateral tracking performance for a 3° vertical gyro tilt error prior to localizer capture.

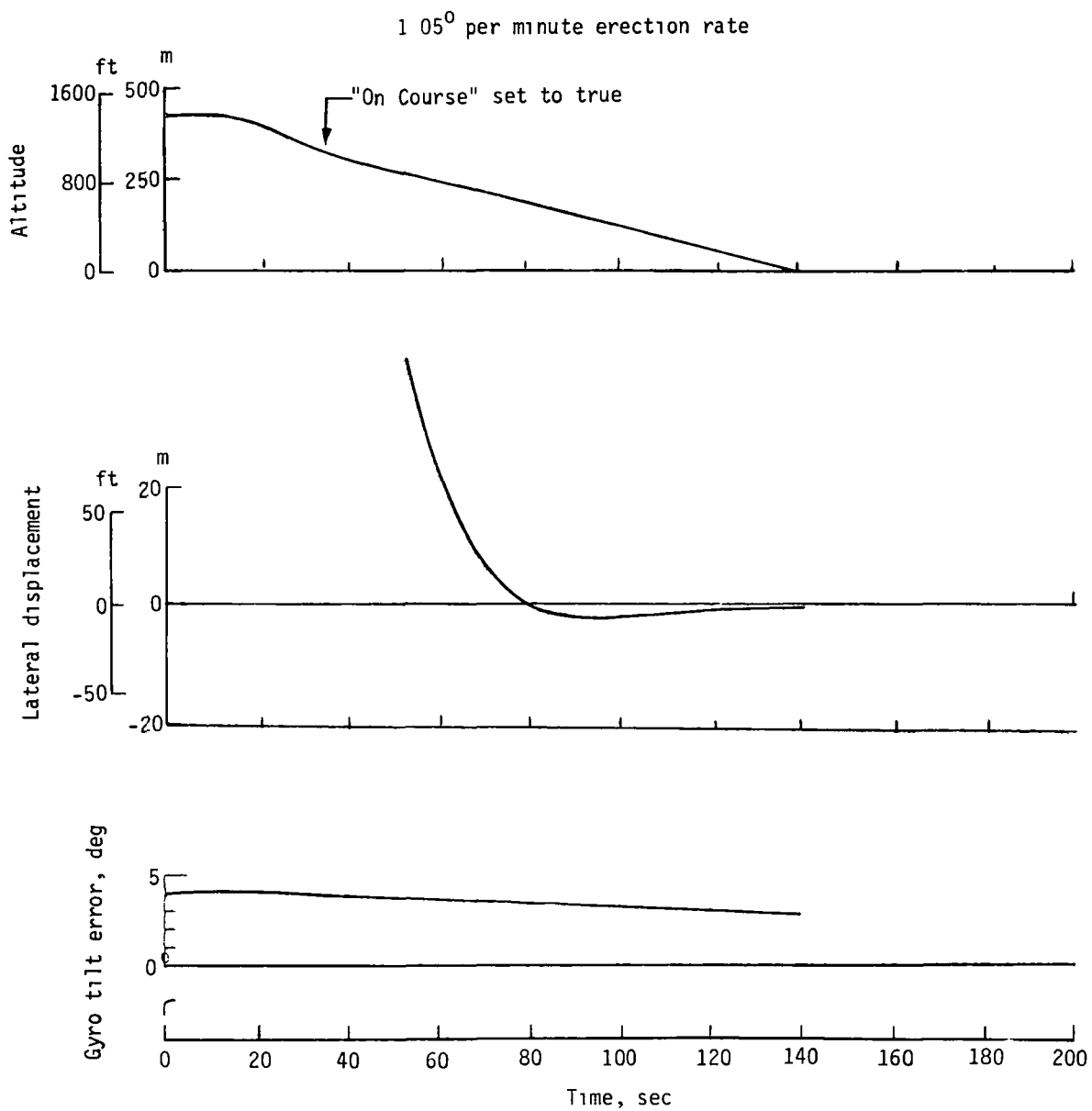


Figure 8.- Lateral tracking performance for a 4° vertical gyro tilt error prior to localizer capture.

1 05° per minute erection rate

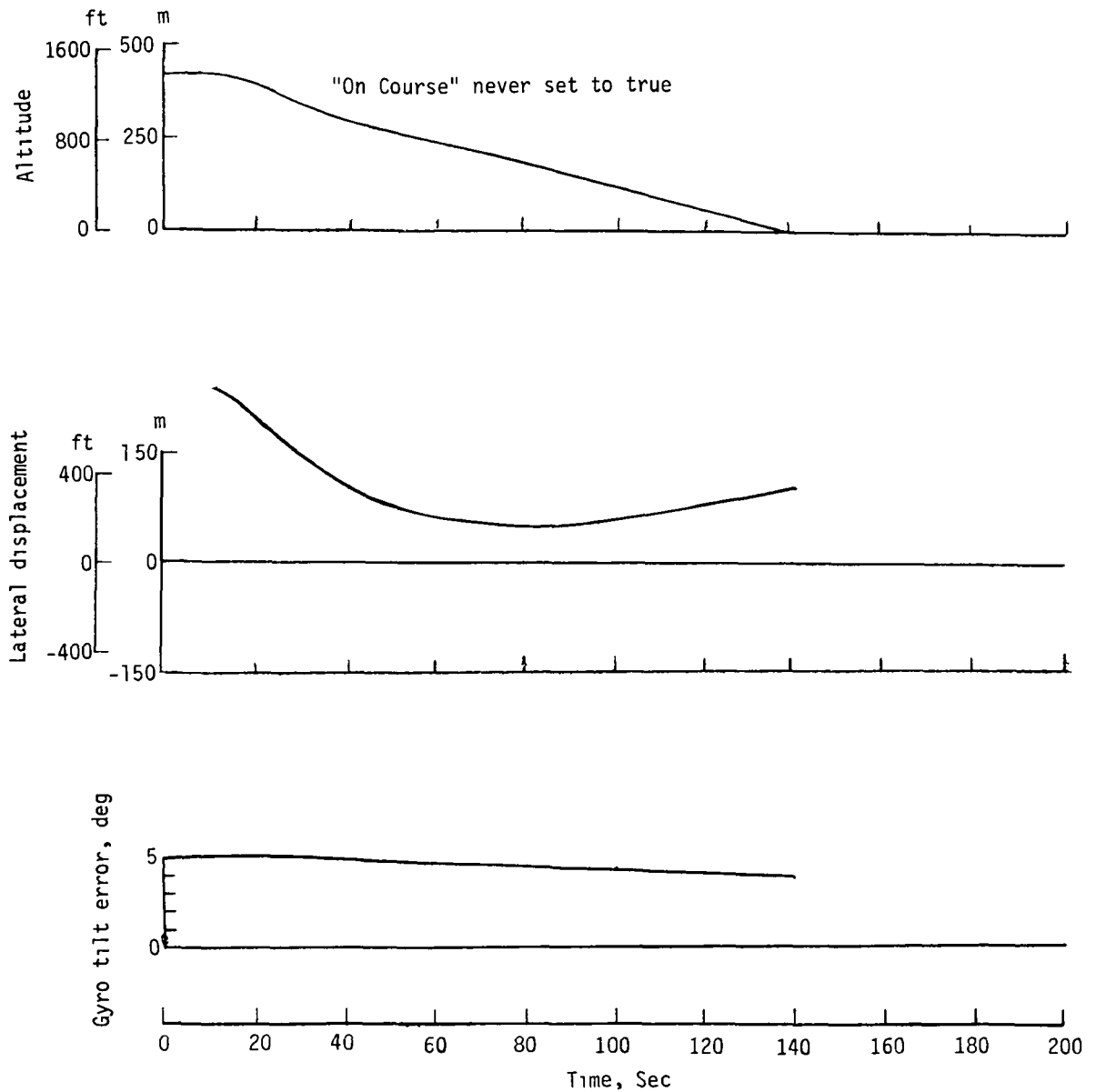


Figure 9.- Lateral tracking performance for a 5° vertical gyro tilt error prior to localizer capture.

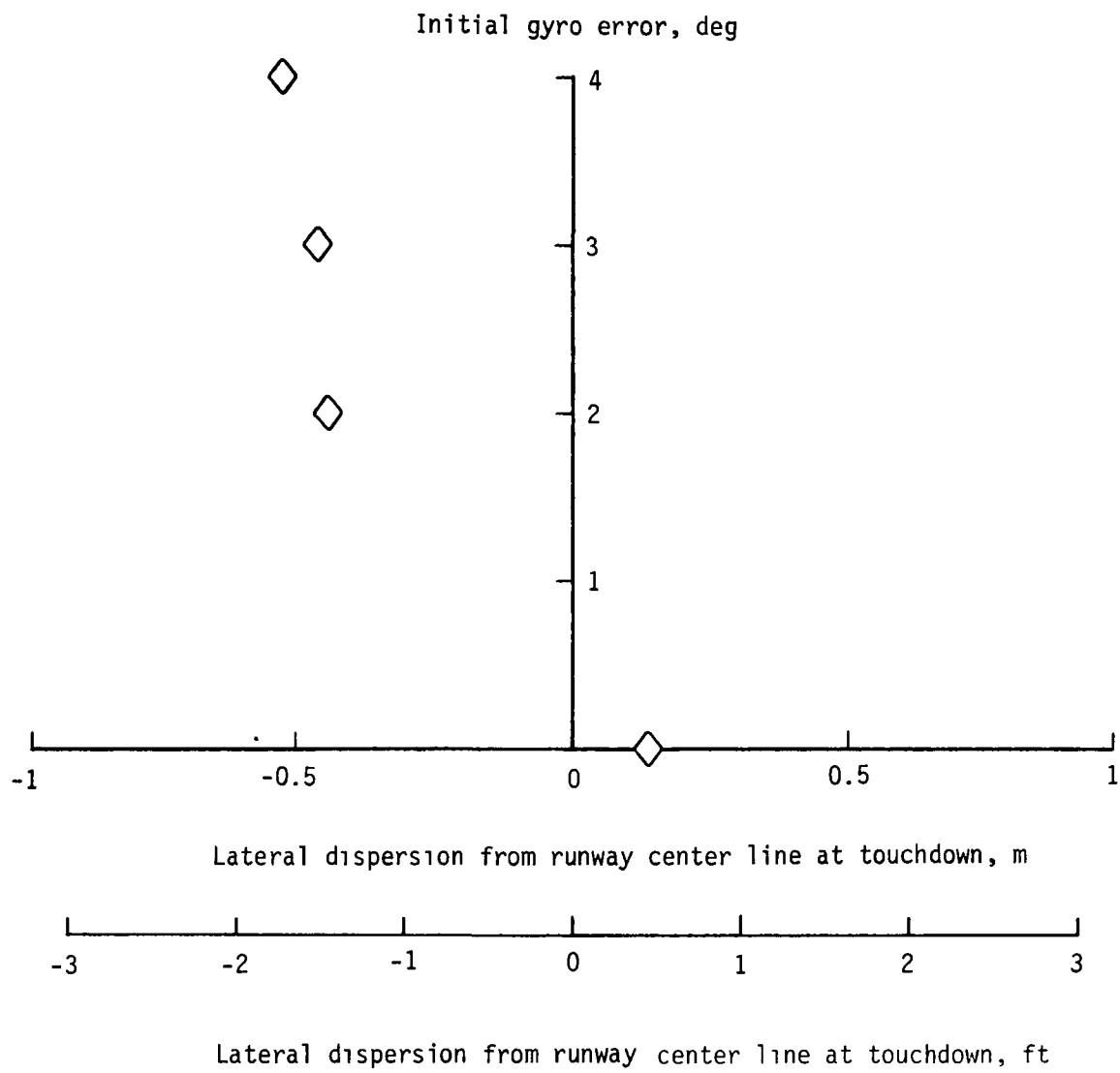
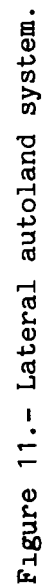


Figure 10.- Touchdown dispersions for various initial gyro verticality errors.



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